# Polymer based thin film coils as a power module of wireless neural interfaces

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*Abstract* – **For the conventional Utah Electrode Array (UEA) to be able to function without transcutaneous wire connections, a kind of power source is needed in an integrated form with the UEA. To develop such wireless neural interfaces, inductive coupling between two coils was used to deliver power to the integrated electronics. The power receiver coil was microfabricated as a polymer based component, and its electrical characteristics and performance in power transmission were investigated in dry condition.**

## I. Introduction

Recently, efforts have been devoted to develop a fully integrated, wireless neural recording device based on the conventional Utah Electrode Array. This will free the patient from the risk of infection associated with a wired connection and allow distribution of a network of interface nodes through the central and peripheral nervous system. To this end, fully integrated neural interfaces need to have a wireless power source and the capability to wirelessly transmit data to/from extracorporeal devices. Inductive coupling between two coils can be a solution to provide power and data to the implanted electronics. In this paper, coils serving as a power module to supply the integrated neural interface were fabricated, characterized, and its power transfer performance was tested in laboratory condition.

## II. Fabrication of power coils

Taking into account simulation results [1], technological considerations, the UEA re-routing strategy, and the device assembly process, several optimized coil designs were manufactured based on polyimide. Single and double layer coils were manufactured with line width and spacing of 15-20 µm and a thickness of larger than 10 µm of the Au layer.

PI/Au coils were fabricated on a 4” Si wafer. The process is based on a release layer which is deposited directly on the monitor wafers. This layer based on non-filled thermoplastic polymer is necessary for the final separation of the thin film PI/metal stack. Each wafer carries 100 coils with different designs. The process for the double layer coils consists of four plating steps, starting with the polymer layer and ending with the formation of Ni/Au interconnection pads. The plating process is done using the combination of sputtering TiW/Au and deposition of photoresist (AZ 9000 from AZ Electronic Materials). The PI is a polyamic acid type from Fuji-Film. The left of Figure 1 shows an optical microscope image of an electroplated Au coil. Six different geometries of Au coils were electroplated on PI substrates. The right of Figure 1 shows the cross section of a 15 µm/15 µm width/space double-layered PI coil as an example of the fabricated coils. With this width and spacing, 60 turns could be realized on each layer.

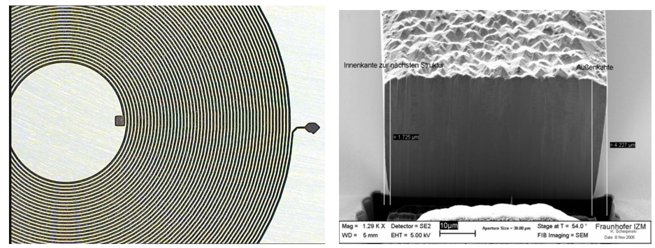


Figure 1: Optical microscope image of an electroplated Au-coil with 15 µm width and 15 µm space on polymer layer (left), FIB cut of Au coil (right).

To avoid undesirable high inter-winding capacitance that may exist between coil layers when using double layer coils, stackable coils were proposed. These can be switched in parallel or series in order to tune the coil parameters and therefore the resonant frequency of the circuit. The coil stack for inductive power coupling consists of two polyimide based electroplated Au coils with 60 turns each. The coils are glued on a low-temperature-co-fired-ceramic (LTCC) ferrite platelet to increase the $Q$ factor. An electrical interconnect layout was designed to connect the PI based Au coil through vertical spacers to the integrated electronics and other surface mount device (SMD) components. The schematic in Figure 2 (left) depicts the routing layout and dimensions of the package. To compensate for varying parasitic capacitances and voltage gain, a jumper can be used to operate the coils in three ways: 1) a double layer coil, 2) a single layer coil, and 3) two stacked coils (a double and a single or two single coils). A mounted coil on a test module is shown in Figure 2 (right).

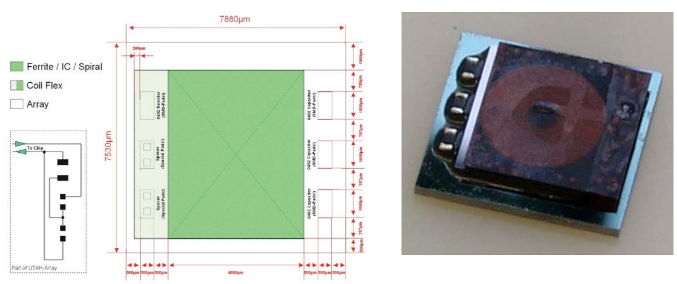


Figure 2: Schematic of the dimensions of the package; the two spacers and the jumper on the left side can be used for single or double coil assembly, the circuit plan is shown on the bottom left side (left), light microscopy image of a fully assembled test module with mounted coil/ferrite (right).

## III. Characterization and test of coils

All six geometries of the polyimide based coils were tested with and without the LTCC ferrite platelet backing. The coils were mounted and wire bonded on standard DIP40 ceramic packages for convenience in testing. The coils were



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mounted outside the cavity of the packages to avoid eddy currents associated with the conductive substrate in the cavity.

Inductance and resistance measurements were taken using a Stanford Research Systems SR715 LCR meter at 10 kHz. The results are shown in Table I. Because inductance and resistance are somewhat frequency dependant, the $Q$ factor was measured empirically at the resonant frequency of 2.64 MHz. The method for this measurement is described in more detail below. Coil type A in Table I has 51 windings with a width of 20 µm and space between windings of 15 µm. Type B also has 51 turns, but with width/spacing of 15 µm/20 µm, and type C has 60 turns with width/spacing of 15 µm/15 µm. All three types have a diameter of 5 mm. Single and double layer versions of these make up the six geometries investigated. Each coil type was tested with and without ferrite backing, resulting in twelve total coil configurations.

For the same number of turns, coils of type B have more series resistance than those of type A. This is due to the smaller cross sectional area of the windings. Type C coils have more turns and thus have greater inductance and greater resistance. Double layer coils had approximately four times the inductance of similar single layer coils due to having double the number of turns. The addition of the ferrite backing resulted in an average increase in inductance of 64 % without significantly affecting resistance. This led to an average increase in the $Q$ factor of 82 %.

The $Q$ factor was measured at resonance using the relation $Q = f_0/\mathrm{BW}$, where $f_0$ is the resonant frequency of 2.64 MHz and BW is the -3 dB bandwidth of the coil. This was accomplished by first selecting appropriate capacitors for each coil to resonate at $f_0$. These capacitors were chosen empirically to avoid discrepancies due to parasitic capacitances in the test setup. A frequency sweep was then performed to determine the -3 dB point on either side of the peaking. BW is the difference between the two -3 dB frequencies. The frequency sweep was performed using an Agilent 33120A function generator with 10 $V_{pp}$ amplitude. This supply has a fixed output source resistance of 50 Ω, which is comparable to the series resistance of the coils. Therefore, a 1 MΩ resistor was inserted in series with the coil to minimize the potential distortion of data due to frequency-dependant changes in coil inductance and resistance.

Next, each coil was tested using resonant capacitors to supply power to the integrated electronics (currently packaged separately) [2]. The combined load of these electronics was about 3 mA. It was found that higher inductance and higher $Q$ coils were most effective for powering the electronics. Approximately 4.5 V is required at the receive end to provide suitable headroom for a rectified, regulated 3.3 VDC power supply. All three double-layer, ferrite-backed coils were able to supply sufficient voltage to power the electronics. The type A coil was the most efficient, able to provide the necessary 4.5 V at a distance of up to 12 mm.

TABLE I. ELECTRICAL MEASUREMENTS

| Coil Configuration | | | Measurements | | |
|---|---|---|---|---|---|
| | | | ***L (µH)*** | ***R (Ω)*** | ***Q @ 2.64 MHz*** |
| Single Layer | No Ferrite | A[a] | 7.29 | 33.5 | 2.49 |
| | | B | 7.41 | 40.5 | 2.18 |
| | | C | 10.3 | 50.5 | 2.78 |
| | With Ferrite | A | 11.3 | 36.7 | 4.98 |
| | | B | 12.1 | 40.0 | 4.80 |
| | | C | 16.9 | 50.5 | 5.08 |
| Double Layer | No Ferrite | A | 29.2 | 74.8 | 5.62 |
| | | B | 29.1 | 88.6 | 4.98 |
| | | C | 40.2 | 111.3 | 5.18 |
| | With Ferrite | A | 46.9 | 74.5 | 9.10 |
| | | B | 49.8 | 88.5 | 8.25 |
| | | C | 68.5 | 113.2 | 8.52 |

a. Coil Type A has 51 turns, winding width of 20 µm, and space between windings of 15 µm. Type B has 51 turns, width/spacing of 15 µm/20 µm; type C has 60 turns with 15 µm/15 µm.

## IV. CONCLUSIONS

In this work, power coils to supply power to the integrated wireless neural interface were fabricated and characterized, and its power transmission performance was fully tested in laboratory condition. The fabricated Au thin film coils based on polyimide can be switched between single layer, double layer, or two stacked coils with the help of a properly designed packaging layout. The most efficient coil type, a double layer coil with 51 turns, width/spacing of 20 µm/15 µm, and a ferrite plate underneath showed an inductance of 46.9 µH and $Q$ factor of 9.10 at 2.64 MHz, resulting in sufficient power supply to the electronics, e.g. greater than 4.5 V over a distance of up to 12 mm.


## ACKNOWLEDGMENTS

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